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Advanced Optical Instrumentation for Ultra-compact, Radiation Hard, Fast-timing EM Calorimetry

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To address the challenges of providing high performance calorimetry and other types of instrumentation in future experiments under high luminosity and difficult radiation and pileup conditions, R&D is being conducted on promising optical-based technologies that can inform the design of future detectors, with emphasis on ultra-compactness, excellent energy resolution and spatial resolution, and especially fast timing capability.

The strategy builds upon the following concepts: use of dense materials to minimize the cross sections and lengths (depths) of detector elements; maintaining Molière Radii of the structures as small as possible; use of radiation-hard materials; use of optical techniques that can provide high efficiency and fast response while keeping optical paths as short as possible; and use of radiation resistant, high efficiency photosensors.

High material density is achieved by using thin layers of tungsten absorber interleaved with active layers of dense, highly efficient crystal or ceramic scintillator. Several scintillator approaches are currently being explored, including rare-earth 3+ activated materials Ce^{3+} and Pr^{3+} for brightness and Ca co-doping for improved (faster) fluorescence decay time.

Light collection and transfer from the scintillation layers to photosensors is enabled by the development and refinement of new waveshifters (WLS) and the incorporation of these materials into radiation hard quartz waveguide elements. WLS dye developments include fast organic dyes of the DSB1 type, ESIPT (excited state intermolecular proton transfer) dyes having very large Stokes' Shifts and hence very low optical self-absorption, and inorganic fluorescent materials such as LuAG:Ce, which is noted for its radiation resistance.

Optical waveguide approaches include thick-wall quartz capillaries containing WLS cores to: (1) provide high resolution EM energy measurement; (2) with WLS materials strategically placed at the location of the EM shower maximum to provide high resolution timing of EM showers, and (3) with WLS shifter elements placed at various depth locations to provide depth segmentation measurement of the EM shower development.

Light directly from the scintillators or indirectly via wave shifters is detected by pixelated, Geiger-mode photosensors that have high quantum efficiency over a wide spectral range and designed to avoid saturation. These include the development of very small pixel (5-7 micron) silicon photomultiplier devices (SiPM) operated at low gain and cooled (typically -35℃ or below), and longer-term R&D on photosensors based upon large band-gap materials including GaInP. Both efforts are directed toward improved device performance in high radiation fields.

The main emphases of this research program are: (1) the bench, beam and radiation testing of individual scintillator, wave shifter and photo sensing elements; and (2) by combining these into ultra-compact modular structures, to characterize and assess their performance for measurement of energy, fast timing, and depth segmentation. Recent results and program plans will be presented.

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